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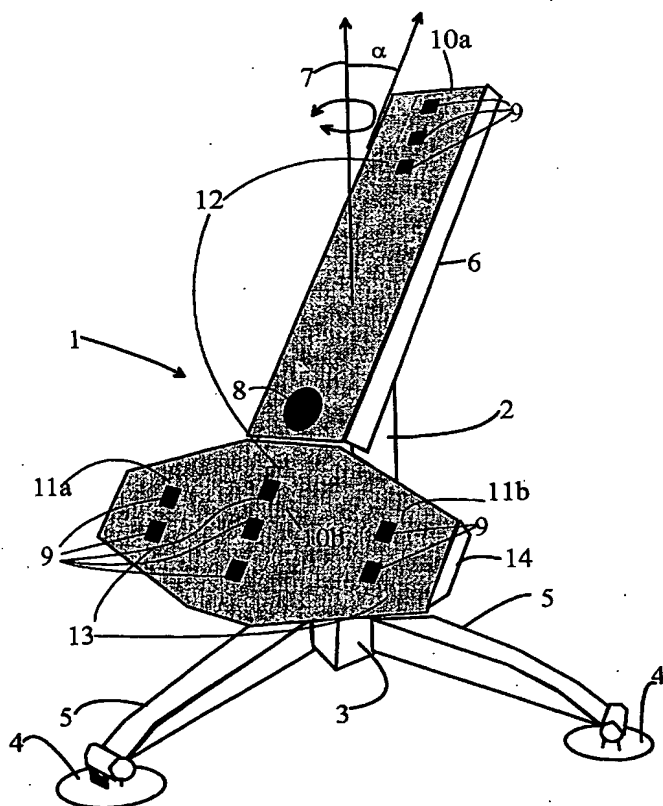
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[Continued on next page]

(54) Title: ANTENNA SYSTEM AND METHOD FOR MEASURING THE AZIMUTH AND ELEVATION ANGLES OF AN  
ACTIVE, SIGNAL SENDING RADIOSONDE



(57) Abstract: The present invention relates to an antenna system and method. The antenna system for measuring azimuth and elevation angles of an active, signal sending radiosonde (31), comprises a first passive antenna group (13) comprising at least two antenna arrays (11a, 11b), the direction pattern of which is wide at least in elevation plane for measuring azimuth angle of the radiosonde (31) based on the phase differences between the antenna arrays (11a, 11b), a second passive antenna group (12) comprising at least two antenna arrays (10a, 10b), the direction pattern of which is wide at least in elevation plane for measuring the elevation angle of the radiosonde (31) based on the phase differences between the antenna arrays (10a, 10b) and the rotational position of the antenna field (1), and at least one third antenna (8) having high gain for receiving the telemetry signal, the direction pattern of which element (8) is narrow in azimuth plane and wide in elevation plane. According to the invention first (13) and second (12) antenna groups form a solid antenna field (1), and antenna field (1) is fixedly tilted in a predetermined elevation position.

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*For two-letter codes and other abbreviations, refer to the "Guidance Notes on Codes and Abbreviations" appearing at the beginning of each regular issue of the PCT Gazette.*

Antenna system and method for measuring the azimuth and elevation angles of an active, signal sending radiosonde

The present invention relates to an antenna structure according to the preamble of claim 1.

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The invention also relates to a method according to the preamble of claim 12.

The invention relates also to a method for measuring the azimuth and elevation of an active, signal sending radiosonde.

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The present invention is related to atmospheric sounding systems, in which the properties of the atmosphere are measured in-situ by independent, self powered active components typically called radiosondes including a radio transmitter. Typical features for this technique are inactive (non-sending) receiving antennas and the fact that the measuring device (radiosonde) is either lifted or dropped through the space to be measured.

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Parameters measured in-situ by sensors of the radiosonde, such as air pressure, temperature and relative humidity, are transmitted through a telemetry link to a receiving station. Other parameters of interest are wind speed and wind direction that can be measured by using navigation aid networks such as GPS or Loran-C, by a primary or secondary radar, or by a passive (non-sending) and independent (no navigation aid networks used) radiotheodolite. Height of the radiosonde can be calculated from the air pressure, temperature and humidity data.

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The object of the invention is to determine the azimuth and elevation angles of an active radiosonde in a three dimensional space with a passive (non-sending) antenna structure independent of navigation aid networks. A typical application of the invention is to locate a radiosonde launched into the atmosphere with the help of a balloon filled with hydrogen or helium. Radiosonde azimuth and elevation angles are determined from the received radiosonde signal.

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Wind speed and direction can be calculated from consecutive azimuth and elevation angles and height of the radiosonde.

Prior solutions in the 1680 MHz meteorological frequency band track the radiosonde mechanically both in the azimuth and elevation directions. The disadvantage of this solution is the complicated and expensive mechanical receiving antenna structure.

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Another disadvantage of the prior solutions is the disability to attenuate ground reflections enough when the radiosonde signal is received from a low elevation angle.

10

It is an object of the present invention to overcome the problems of the prior solutions and to provide an entirely novel type of antenna structure and a method for determining the azimuth and elevation angles of a radiosonde.

15

The goal of the invention is achieved by a fixedly backwards tilted antenna field, in which the antenna elements are assembled on an antenna frame. In one typical embodiment the antenna field is rotated around vertical axis approximately to the direction of the radiosonde while the elevation angle remains essentially constant.

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In another embodiment of the invention there are at least three such fixedly tilted antenna fields that point to different fixed azimuth directions. This solution has no moving parts.

More specifically, the antenna system according to the invention is characterized by what is stated in the characterizing part of claim 1.

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Furthermore, the method according to the invention is characterized by what is stated in the characterizing part of claim 12.

The invention offers significant benefits.

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By attenuating the ground reflection the azimuth and elevation angles of the radiosonde can be measured more precisely especially when the radiosonde is in a low elevation angle.

The mechanics of the antenna structure can be simplified and manufactured at a lower cost. Furthermore the reliability of the system is increased as there are less moving parts.

In the following, the invention will be examined in greater detail with the help of  
5 exemplary embodiments by making reference to the appended drawings in which

Figure 1a shows in a perspective view a rotatable antenna structure in accordance with the invention.

10 Figure 1b shows a simplified version of the embodiment of figure 1a.

Figure 2 shows in a perspective view a stationary antenna structure in accordance with the second embodiment of the invention.

15 Figure 3 shows schematically a balloon borne radiosonde, direct signal, ground reflection, rotatable antenna structure and a typical radiation pattern with a gain pattern minimum (null) in the direction of the ground reflection.

Figure 4 shows a polar-plot of a typical radiation pattern for a two-element antenna array  
20 with a gain pattern minimum (null) in the direction of the ground reflection.

Figure 5 shows schematically as a side view the phasing of a two-element antenna array.

In accordance with figure 1 the essentially planar antenna field 1 comprises a vertical  
25 antenna group 12 and a horizontal antenna group 13. The vertical antenna group 12 comprises at least two antenna arrays 10a and 10b positioned above each other. In this solution each array comprises three antenna elements 9. The direction pattern of these arrays 10a and 10b is wide in elevation plane.

30 The vertical antenna group 10a and 10b is used for determining the elevation angle of the radiosonde based on the phase differences of the received radiosonde signal between the antenna arrays 10a, 10b.

Respectively horizontal antenna group 13 comprises two horizontal antenna arrays 11a and 11b positioned at least essentially symmetrically around the vertical center line of the antenna field 1. In this solution each array comprises two or more antenna elements 9. The direction pattern of these arrays 11a and 11b is also wide in elevation plane.

5

The azimuth angle of the radiosonde is determined with arrays 11a and 11b based on the phase differences between the antenna arrays 11a, 11b and the rotational position of the antenna field 1.

- 10 One preferable embodiment 1 of the invention includes only one rotatable support frame divided in upper 6 and lower parts 14. The antenna field 1 with its frame 2 is mounted on a stationary tripod 3 having circular support plates 4 at the end of its legs 5. An independent antenna 8 is for radiosonde telemetry. The antenna frame is rotatable around the vertical axis 7 for directing the antenna field 1 approximately to the direction of the
- 15 radiosonde. The azimuth angle is measured with the horizontal antenna group 13 on the lower part 14 of the frame and elevation angle with help of the vertical antenna group 12 positioned on the upper and lower parts 6 and 14 of the frame. A simplified version of the antenna groups required for the angle measurement is presented in the figure 1b. The tilting angle  $\alpha$  is typically  $30^\circ$ . The term "fixed tilting" or "fixed tilting angle" in this context
- 20 means also solutions, where a small vibrational deviation of the tilting angle is allowed for example due to the wind.

Due to the antenna group 13 for azimuth measurement, the antenna field 1 forms an inverted T- or L-shape. With this solution a low center of gravity and wind load can be

25 achieved. Obviously, the azimuth antenna group 13 can be positioned also in the upper part 6 or center of the antenna field 1 within the scope of the inventive idea, whereby a T-, inverted L- or plus (+) shape is formed. The invention does not limit the azimuth and elevation antenna groups to be perpendicular to each other or the ground, thereby allowing, for instance, also an X-shape antenna field.

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Radiosonde telemetry reception is independent of azimuth and elevation measurements. The telemetry signal is received by a separate high gain directional antenna 8. The

direction pattern of the antenna 8 is typically narrow in azimuth plane and wide in elevation plane.

Figure 1b represents a simplified version of the antenna structure of figure 1a. In this version each antenna array is replaced by single antenna elements 9.

Figure 2 represents another embodiment of the invention in a form of a fixed pyramid shaped antenna with four tilted antenna fields 14. The azimuth angle is measured with horizontal antenna group 20 comprising two antenna arrays 18a and 18b at the bottom of the pyramid. Arrays include two or more antenna elements 16. Elevation angle is measured with vertical antenna group 19 comprising two vertically positioned antenna arrays 17a and 17b in the upper and lower parts of the pyramid. The telemetry signal is received by a separate directional antenna 15 positioned on the top of the pyramid.

In both of the before described solutions the azimuth angle is determined from the measured phase difference of at least two antenna elements or arrays in the horizontal direction (horizontal groups 13 or 20) and the direction of the antenna field 14.

The elevation angle is determined from the measured phase difference of at least two antenna elements or arrays essentially in the vertical direction (vertical groups 12 or 19).

In accordance with figure 3 the purpose of the antenna system 34 is to obtain a direct radio signal 32 from the radiosonde 31. When the radiosonde 31 is in a low elevation angle, ground reflection 30 coming from the (negative) mirror angle has been a major factor degrading the performance of prior solutions. The present invention decreases this problem by aligning a gain pattern minimum 35 (null) of the radiation pattern 33 to the direction of the ground reflection 30. The direction is typically determined experimentally for different elevation angles by aligning the main beam by phased array techniques such that the ground reflection is minimized.

30

In accordance with figure 4 the gain pattern minimum (null) is formed by an antenna array (10a, 10b, 11a, 11b, or 17a, 17b, 18a, 18b) which consists of at least two antenna elements

(9 or 16). Gain pattern minimum (null) 30 is directed by modifying the signal phase and amplitude of each antenna element in the array (beamforming).

- 5 According to figure 5 the sum of the modified signals represents the antenna array that can now be regarded as a single antenna element with a more suitable radiation pattern. A gain pattern minimum (null) is formed separately for each of the antenna arrays in the horizontal and vertical groups (12, 13 or 19, 20).

$$s = s_{a1} A e^{j \frac{\phi}{180} \pi} + s_{a2} A e^{-j \frac{\phi}{180} \pi}, \text{ where } \phi \text{ is a phase shift}$$

- 10 Phase shift is designed experimentally for different elevation angles (radiation patterns). Antenna beam forming is explained in more detail e.g., in reference Robert J. Mailloux, Phased Array Antenna Handbook, Chapters 2 and 3, 1994 Artech House, Inc, ISBN 0-89006-502-0.
- 15 In accordance with figure 6 the angle of arrival can be measured with two identical antennas A1 and A2 using interferometric principle explained in more detail e.g., in reference Englar, Mango, Roettcher, Watters, FINAL REPORT FOR THE MININTRACK TRACKING FUNCTION DESCRIPTION, Volume 1, March 1973, NASA-TMX-66213. If the base length ( $b$ ) is less or equal than half of the wavelength ( $\lambda$ )
- 20  $/2$ ) the unambiguous angle of arrival ( $-90^\circ < \alpha < 90^\circ$ ) can be measured. When the phase difference ( $\phi$ ) between antenna A1 and A2 has been measured ( $-180^\circ < \phi < 180^\circ$ ), the direction of arrival (DOA) can be calculated as :

$$\alpha = \arcsin\left(\frac{x}{b}\right),$$

$$\text{where } x = \frac{c \phi}{f * 360^\circ},$$

$$c = \text{speed of light} \quad \text{and} \quad f = \text{signal frequency}.$$

- 25 Instead of the planar antenna field 1 or 14 shown in figures 1a, 1b and 2 the antenna field may be also convex, concave or for example stepped. In the rotatable embodiments of figures 1a and 1b all the antennas, antenna arrays and antenna elements are positioned on this uniform rigid antenna field 1 regardless of the shape of the antenna field. In the embodiment of figure 2 the telemetry antenna 15 is not included to this antenna field 14.



In this application with wide beam is meant beam widths greater than  $120^{\circ}$ .

Respectively narrow beam means beam widths smaller than  $30^{\circ}$ .

## CLAIMS

1. An antenna system for measuring azimuth and elevation angles of an active, signal sending radiosonde (31), which antenna system comprises

5

- a first passive antenna group (13) comprising at least two antenna arrays (11a, 11b), the direction pattern of which is wide at least in elevation plane for measuring azimuth angle of the radiosonde (31) based on the phase differences between the antenna arrays (11a, 11b),

10

- a second passive antenna group (12) comprising at least two antenna arrays (10a, 10b), the direction pattern of which is wide at least in elevation plane for measuring the elevation angle of the radiosonde (31) based on the phase differences between the antenna arrays (10a, 10b) and the rotational position of the antenna field (1), and

15

- at least one third antenna element (8) having high gain for receiving the telemetry signal, the direction pattern of which element (8) is narrow in azimuth plane and wide in elevation plane,

characterized in that

20

- first (13) and second (12) antenna groups form a solid antenna field (1), and  
- antenna field (1) is fixedly tilted in a predetermined elevation position.

25

2. The antenna system of claim 1, characterized in that the third antenna (8) belongs to the antenna field (1).

3. The antenna system of claim 1 or 2, characterized in that the antenna field is essentially planar.

30

4. The antenna system of any of the previous claims or their combination, characterized in that the gain pattern minimum (35) (null) of each antenna array (10a, 10b, 11a, 11b) is aligned to the direction of the ground reflection (30).

5. The antenna system according to any previous claim or their combination, **characterized** in that the antenna system comprises means for rotating the antenna field (1) around vertical axis (7) approximately to the direction of the radiosonde (31) while the elevation angle remains essentially constant.
- 5
6. The antenna system according to any previous claim or their combination, **characterized** in that radiosonde (31) telemetry reception is independent of azimuth and elevation measurements.
- 10 7. The antenna system according to any previous claim or their combination, **characterized** in that the antenna field (14) is fixed in elevation and azimuth direction, and that the system comprises at least three antenna fields (14) pointing to different azimuth directions.
- 15 8. The antenna system of claim 7, **characterized** in that the gain pattern minimum (null) of each antenna array (17a, 17b, 18a, 18b) is aligned to the direction of the ground reflection.
9. The antenna system of claim 7 or 8, **characterized** in that radiosonde telemetry reception (15) is independent of azimuth and elevation measurements.
- 20
10. The antenna system according to any previous claim or their combination, **characterized** in that the antenna field (1) is fixedly tilted backwards.
11. The antenna system according to any previous claim or their combination,
- 25 **characterized** in that the antenna field (1) forms an inverted letter T.
12. A method for measuring azimuth and elevation angles of an active, signal sending radiosonde (31), in which method
- 30 - the azimuth angle of the radiosonde (31) is measured based on the phase differences of the received radiosonde signals between the antenna arrays (11a, 11b) and the rotational position of the antenna field (1) with a first

- passive antenna group (13) comprising at least two antenna arrays (11a, 11b), the direction pattern of which is wide at least in elevation plane,
- the elevation angle of the radiosonde (31) is measured based on the phase differences of the received radiosonde signals between the antenna arrays (10a, 10b) with a second passive antenna group (12) comprising at least two antenna arrays (10a, 10b), the direction pattern of which is wide at least in elevation plane, and
- the telemetry signal is received with at least one third antenna element (8) having high gain, the direction pattern of which element (8) is narrow in azimuth plane and wide in elevation plane,

**characterized** in that

- first (13) and second (12) antenna groups form a solid antenna field (1), and
- antenna field (1) is fixedly tilted in a predetermined elevation position.

13. The method of claim 12, **characterized** in that the third antenna (8) belongs to the antenna field (1).

14. The method according to any previous method claim or their combination, **characterized** in that the gain pattern minimum (null) of each antenna array (17a, 17b, 18a, 18b) is aligned to the direction of the ground reflection.

15. The method according to any previous method claim or their combination, **characterized** in that radiosonde telemetry reception is independent of azimuth and elevation measurements.

16. The method according to any previous method claim or their combination, **characterized** in that the antenna system is rotated around vertical axis (7) approximately to the direction of the radiosonde (31) while the elevation angle remains essentially constant.

17. The method according to any previous method claim or their combination, characterized in that the antenna field (1) is fixedly tilted backwards.

5 18. The method according to any previous method claim or their combination, characterized in that the antenna field (14) is fixed in elevation and azimuth direction, and that the system comprises at least three antenna fields (14) pointing to different azimuth directions.

10 19. The method according to claim 18, characterized in that the gain pattern minimum (null) of each antenna array (17a, 17b, 18a, 18b) is aligned to the direction of the ground reflection.

20. The method according to claim 18 or 19, characterized in that radiosonde telemetry reception (15) is independent of azimuth and elevation measurements.



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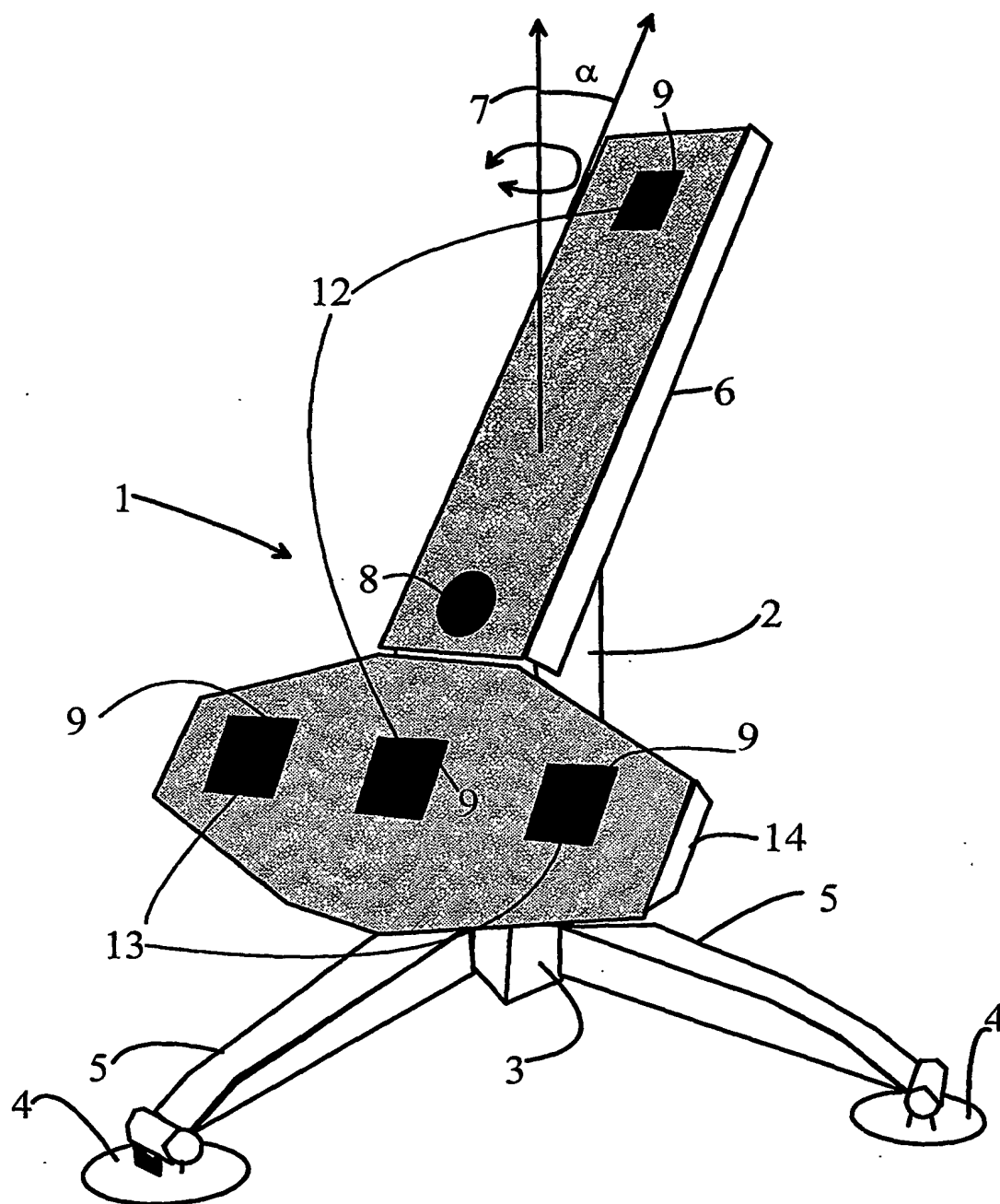


Fig. 1b

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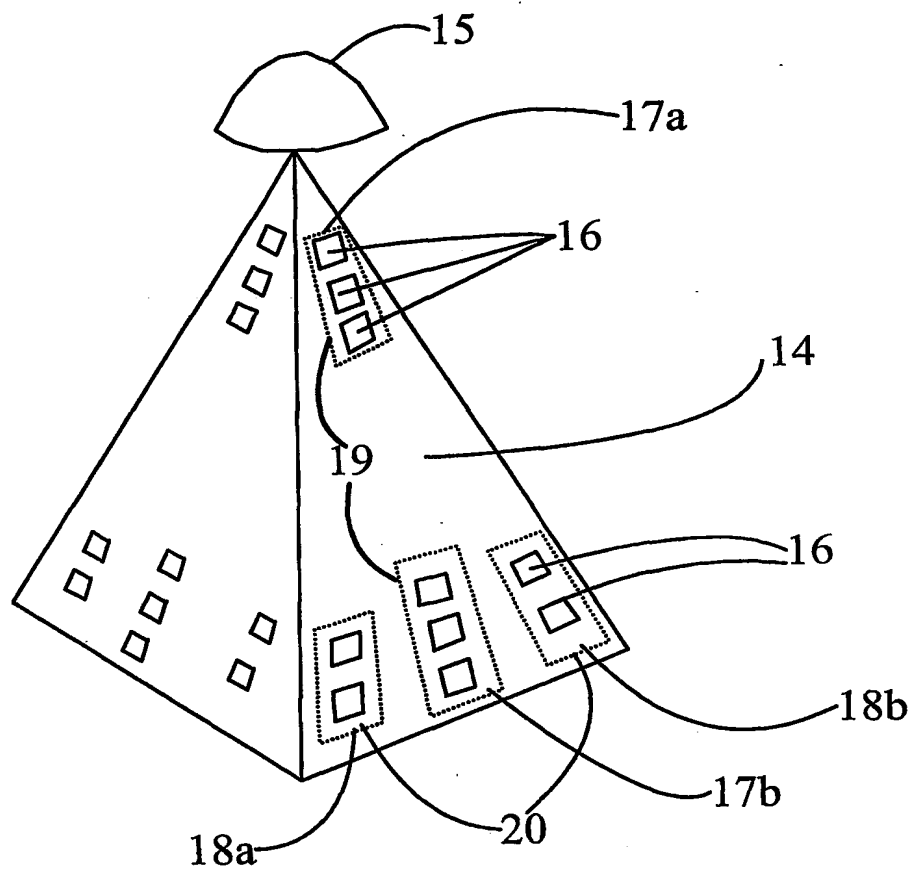


Fig. 2



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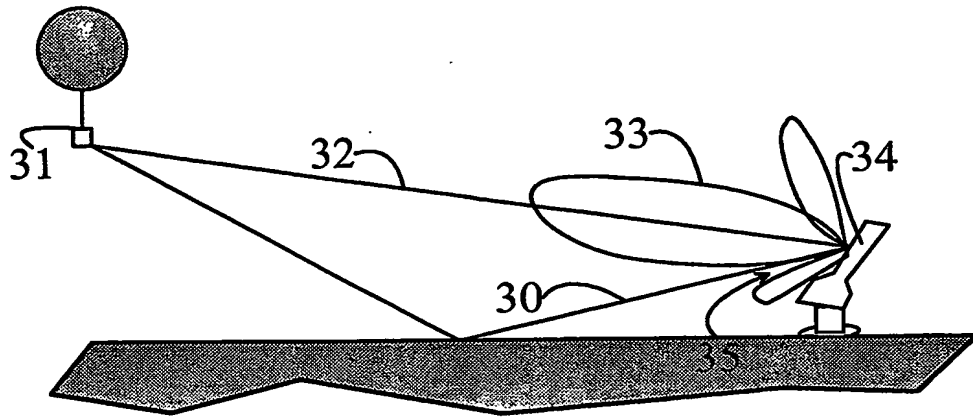


Fig. 3

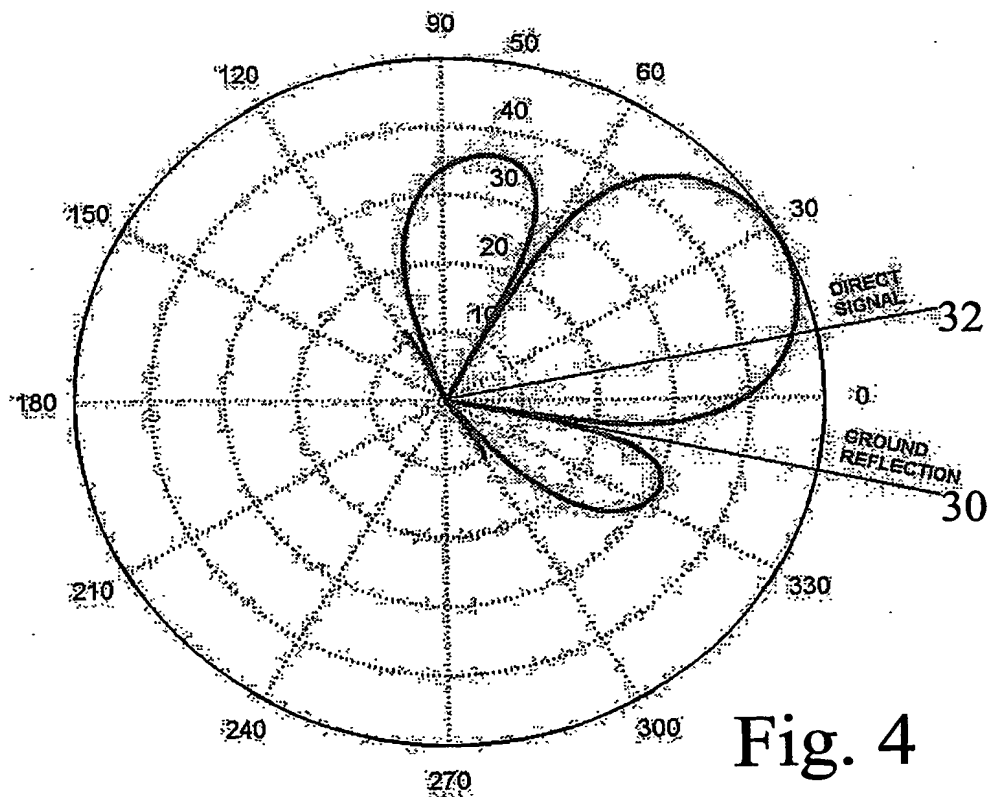


Fig. 4

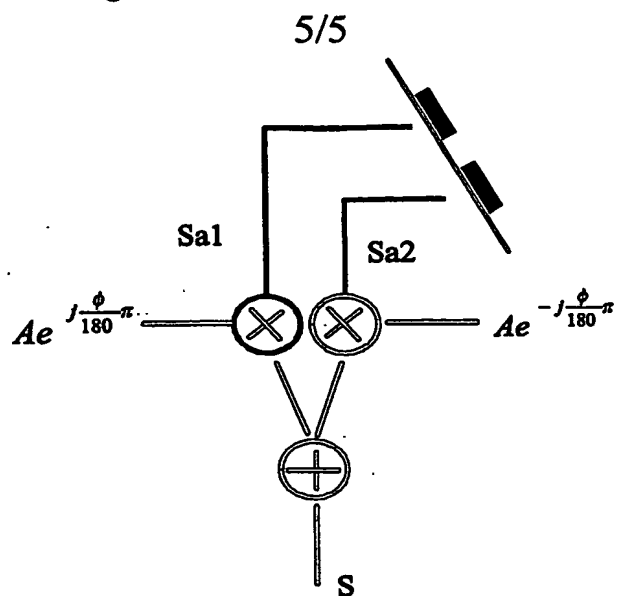


Fig. 5

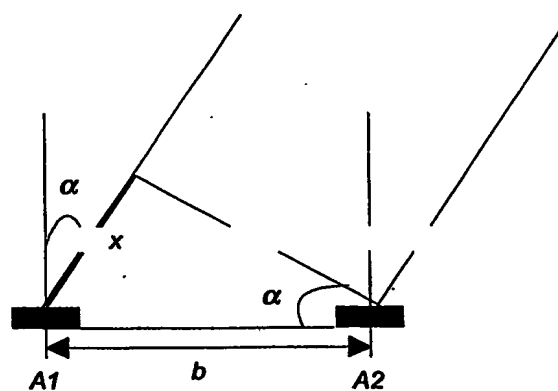


Fig. 6

## INTERNATIONAL SEARCH REPORT

International application No.

PCT/FI 2003/000963

## A. CLASSIFICATION OF SUBJECT MATTER

IPC7: H01Q 3/04, H01Q 21/29, G01S 3/46  
According to International Patent Classification (IPC) or to both national classification and IPC

## B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

IPC7: G01S, G01W, H01Q

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

SE,DK,FI,NO classes as above

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

EPO-INTERNAL, WPI DATA, PAJ, INSPEC

## C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 5053784 A (LASSI HIPPELÄINEN), 1 October 1991 (01.10.1991), column 3, line 22 - column 4, line 54 --	1,4-6,10,12, 14-16
A	US 5245348 A (KUNITOSHI NISHIKAWA ET AL), 14 Sept 1993 (14.09.1993), see the whole document --	1,5,10,12, 16,17
A	US 5486835 A (TERRENCE F. HOCK), 23 January 1996 (23.01.1996), see the whole document --	1,12
A	US 5543811 A (FRANK CHETHIK), 6 August 1996 (06.08.1996), see the whole document --	1,3,7,10

☒ Further documents are listed in the continuation of Box C.☒ See patent family annex.

* Special categories of cited documents:	"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
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International application No.

PCT/FI 2003/000963

## C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
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Information on patent family members

24/12/2003

International application No.

PCT/FI 2003/000963

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